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## Morphological and Star Formation Evolution to $z=1$

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**Abstract.** The decrease, since  $z=1$ , of the rest-frame UV luminosity density is related to global changes in morphology, color and emission lines properties of galaxies. This is apparently followed by a similar decrease of the rest-frame IR luminosity density.

I discuss the relative contribution from the different galaxy morphological types to the observed evolution. The main contributors are compact galaxies observed in large number at optical wavelengths, and the sparse population of extincted & powerful starbursts observed by ISO. This latter population is made of large and massive galaxies mostly found in interacting systems, some of which could be leading to the formation of massive ellipticals at  $z < 1$ .

### 1. Introduction

The evolution of luminosity densities has been examined by Lilly et al (1996), from 600  $I < 22$  galaxies of the Canada France Redshift Survey (CFRS). They found a large decrease by factor 10 of the rest-frame UV luminosity density from  $z=1$  to  $z=0$ . This factor has probably to be lowered to  $\sim 6$ , since recent estimates (Treyer et al, 1998) of the local UV luminosity density are 1.5 times larger than previous estimates based on  $H\alpha$  luminosity density (Gallego et al, 1995).

At  $15\mu\text{m}$  deep counts show a steep slope below  $400\mu\text{Jy}$  (see Elbaz et al, 1999). Associated with the flattening of the deep radio count slope (Fomalont et al, 1991), this suggests the presence of an evolving population at infra-red wavelengths. On the basis of a sample of  $\sim 30$   $15\mu\text{m}$  and radio sources, Flores et al (1999) have shown that the rest-frame IR luminosity density evolves as rapidly as the rest-frame UV luminosity density.

It is important to notice that all these works are based on the observations of relatively luminous galaxies in optical ( $M_B < -20$ ), as well as in IR ( $L_{bol} > 2 \cdot 10^{11} L_\odot$ ). And that the corresponding evaluations of luminosity density evolution are, strictly speaking, related to luminous galaxies. Assuming an unevolved shape of the luminosity function in both UV and IR would provide an equipartition of the energy output (or star formation rate density) between UV and IR light from  $z=1$  ( $\sim 9$  Gyr ago) to the present day (Hammer, 1999), in accordance with bolometric measurements of the background (see Pozzetti et al, 1998).

### 2. Galaxy morphologies and their global evolution

### 2.1. Observations of the Hubble Space Telescope and their limitations

Studies of distant galaxies are limited by the spatial resolution, since 1 pixel of HST/WFPC2 corresponds to  $1h_{50}^{-1}$  kpc at  $z \geq 0.75$ . This provides the most severe limitation to their morphological studies. For example, at  $z=0.75$ , a 5 kpc half-light radius would correspond to only 5 WFPC2 pixels, with an HWHM of only two pixels. This limits the accuracy of bulge/disk deconvolution for a non-negligible fraction of the distant galaxies.

Another limitation is related to redshift dependent effects: for example at  $z=0.9$  the I (F814W) filter samples the rest-frame B band, a color which is more sensitive to star forming regions. 24% of the spirals observed at  $z \sim 0.9$  could be mis-identified as irregulars (Brinchman et al., 1998) when compared to lower  $z$  systems.

Other effects (biases against low surface brightness objects or extincted disks) are caused by the limited photometrical depth reachable in a reasonable exposure time (few hours) and all the above limitations emphasize the need for an optical camera optimized at the diffraction limit on an 8 meter space telescope.

### 2.2. Evolution of averaged properties

Brinchman et al (1998) have presented the HST imagery of  $\sim 340$   $I \leq 22$  galaxies, spanning a redshift range from  $z=0.1$  to  $z=1$ . Galaxy morphologies have been classified by eye as well as through bulge/disk deconvolution. Brinchman et al (1998) quoted that 9% of galaxies at  $0.2 < z < 0.5$  are irregulars, a fraction which reaches 32% at  $0.75 < z < 1$ . The luminous galaxies in the highest redshift bins were much bluer and with a later type than that of a Sbc, conversely to present-day galaxies (Figure 1). Present-day stellar population has an average color  $((B - K)_{AB}=2.5)$  typical of an Sab (see Hammer, 1999).

This trend is followed by a large redshift increase of the rate of emission line galaxies (those with  $W_0(OII) > 15\text{\AA}$ ) from 13% locally to more than 50% at  $z > 0.5$  (Hammer et al, 1997). These properties, taken together, are consistent with the observed rest-frame UV luminosity density, and confirm a declining star formation history since the last 9 Gyr.

## 3. Evolution of galaxies selected by morphology

### 3.1. Ellipticals

The number density evolution of luminous ellipticals is still controversial (see Kauffman et al, 1998). It is an important debate, because the monolithic collapse scenario (see e.g. Bower et al., 1992) predicts their formation at a high redshift conversely to hierarchical models (see White and Rees, 1978) in which massive ellipticals are formed at later times from the collapse of smaller units. The two scenarios are to predict a different star formation history, since a large fraction of the metals are bound in bulges (see Fukugita et al, 1998).

In selecting elliptical galaxies on the basis of their luminosity profiles, Schade et al. (1999) have shown that a color criterion is rather unefficient. This latter likely selects as many disks (possibly with small amounts of dust) as ellipticals. Schade et al. also find no evidence for a decline in space density of ellipticals

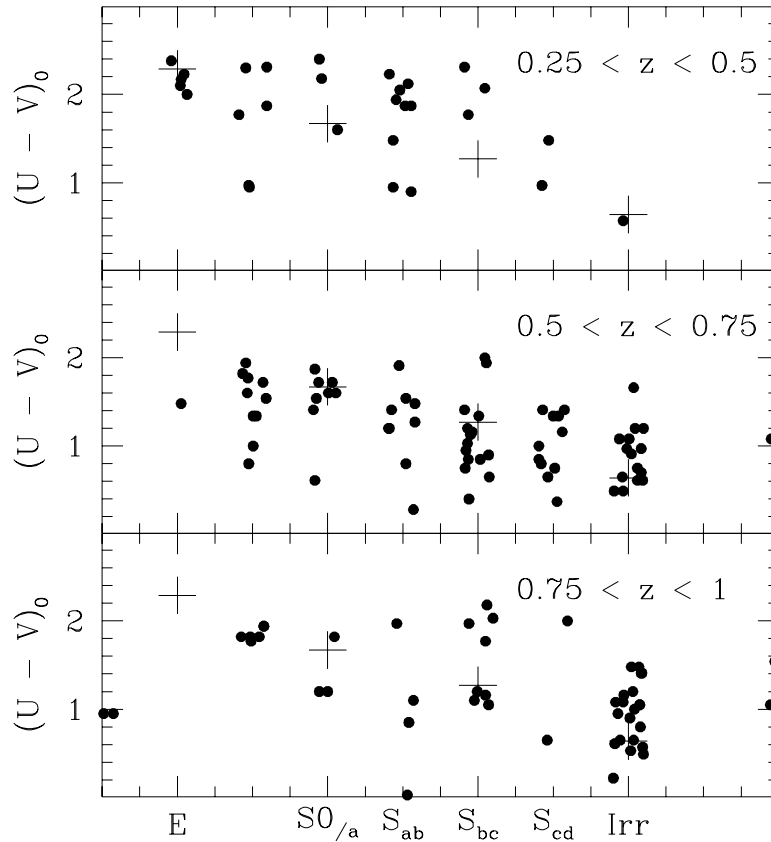


Figure 1. Rest frame  $(U - V)_{AB}$  color versus HST morphological class for  $M_B \leq -20$  CFRS, in three redshift bins. Brinchman et al classification is supported by the comparison with local values (large crosses; Coleman et al, 1980). Most galaxies have an earlier type than Sbc in the lower redshift bin, while the reverse is found at high redshift.

since  $z=1$ , although this conclusion is limited to the small sample of objects in consideration (46 galaxies). More interesting is the fact that a third of the selected ellipticals show significant emission lines, which they interpret as related to small events of star formation at  $z < 1$ , representing the formation of only few percents of the stellar mass.

It is premature to conclude on their number density evolution before a larger sample is gathered. Several biases can also affect the apparent density of ellipticals at high  $z$ , including a possible mis-classification of some S0 with faint disks. Even the detection of small amounts of star formation in  $z < 1$  ellipticals should be taken with caution, because the presence of emission lines seems not to affect their  $(U - V)$  colors (Figure 2). Extinction of hot stars might be at work in these objects, but this should be rather complex to explain the presence of the [OII]3727 emission line. Alternatively, these emission lines could be as well related to the presence of an AGN, which is suggested to be present in most of the massive ellipticals by Hammer et al (1995), on the basis of their radio

inverted spectra. There is however an evidence that elliptical galaxies are not contributing to the observed evolution of the rest-frame UV luminosity density.

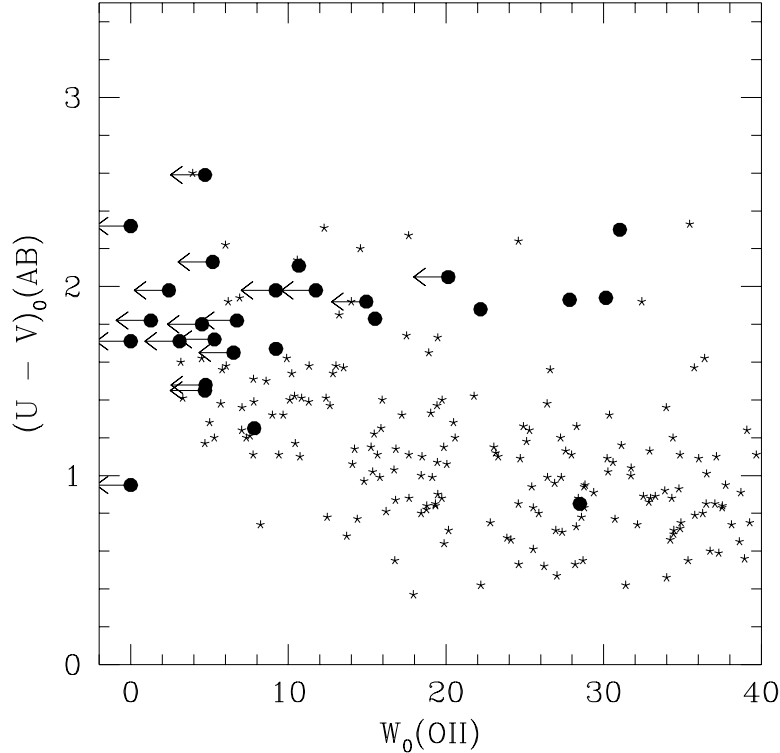


Figure 2. Rest frame  $(U - V)_{AB}$  color versus OII rest frame equivalent widths for  $M_B \leq -20$  from  $z=0.5$  to  $z=1$ . Full dots represents ellipticals selected by Schade et al (1999), and small crosses are other CFRS galaxies observed with the HST. Arrows indicate a limit in the OII equivalent width. In a star forming event, the correlation of the OII EW with  $(U-V)$  color for the CFRS galaxy population is expected. No such a correlation is seen in the selected ellipticals.

### 3.2. Large disks

The density of large disks with  $r_{disk} \geq 3.2h_{50}^{-1}$  kpc is found to be the same at  $z=0.75$  as locally (Lilly et al, 1998). Only a density decrease by less than 30% at  $z=1$  is consistent with the data. Lilly et al (1998) also find that UV luminosity density produced by large disks shows only a modest increase with the redshift. There is however a general shift towards later type for disks in the highest redshift bin.

From long-slit spectroscopy studies, Vogt et al (1997, see also Koo, 1999) show an unevolved Tully Fischer relation for disks at  $z \sim 1$ . However the disk velocity could be affected by the presence of companions at high  $z$  as well as by the geometry and alignment of the slit with the disk major axis (see Amram et al, 1996). Higher resolution spectroscopy associated with integral field unit will

definitively establish the Tully Fisher relation at high redshift.

An important question is to know if the present-day population of galaxies, similar to the Milky Way, was already in place 7 to 9 Gyr ago. Studies of the Milky Way (see Boissier and Prantzos, 1999) as well as the Schmitt law for disks (see Kennicutt, 1998) argue in favor of a rather long duration (3-7 Gyr) for the formation of the bulk of their stars. Number density evolution, Tully Fisher relation and present-day properties of disks, they all suggest a relatively passive evolution of large disks. Redshift changes in large disks appear not to be the main contributors to the evolution of the rest-frame UV luminosity density, as detected in that redshift range. However, it is still unclear if all the disks observed at  $z=1$  are progenitors of present-day disks. Star formation estimates in disks galaxies might be severely affected by extinction, as shown by Gruel et al (1999, in preparation).

#### 4. The major contributors to the observed evolution

##### 4.1. Compact galaxies

The most rapidly evolving population of galaxies detected in the visible is made of small and compact galaxies with half light radius smaller than  $5h_{50}^{-1}\text{kpc}$  (Guzman et al, 1997; Lilly et al, 1998). Their UV luminosity density was 10 times higher at  $z=0.875$  than at  $z=0.375$ , and they correspond to  $\sim 40\%$  of the rest-frame UV luminosity density in the higher redshift bin (Hammer and Flores, 1998). These objects are somewhat enigmatic: their sizes  $-r_{disk} \leq 2.5h_{50}^{-1}\text{kpc}$  and their velocity widths -35 to 150 km/s (Phillips et al, 1997)- are apparently similar to those of local dwarves, while they are 10 to 100 times more luminous than a  $M_B=-17.5$  dwarf.

Guzman (1999) has argued that compact galaxies are the result of bursts in low massive systems (few  $10^9 M_\odot$ ), which would generate the present day population of spheroidal dwarf galaxies. Kobulnicky and Zaritsky (1999) have estimated a range of  $Z=0.3Z_\odot$  to  $Z_\odot$  for the metal abundance of few  $z<0.5$  compact galaxies. These values -as well as their luminosities- are rather consistent with those of local spiral galaxies or of the most massive irregular galaxies. An important question is to know if the very narrow emission lines are indeed sampling the gravitational potential, or if alternatively they are only located in a small area of the galaxies, or being affected by dust or inclination effects. An important fraction (if not all) of the luminous compact galaxies at  $z>0.5$  show evidences for low surface brightness extents (Figure 3), as well as for a noticeable fraction of galaxies with companions. Further studies with large exposure time at 8 meter telescope are required to study their continuum properties (absorption lines).

##### 4.2. Interacting and starbursting galaxies detected by ISO

During a follow-up study with ISOCAM of the CFRS, Flores et al (1999) have detected galaxies with strong emission at both radio and mid-IR wavelengths. They interpret them as being strong star forming galaxies with SFR from 40 to  $250 M_\odot \text{yr}^{-1}$ , most of their UV light being reprocessed by dust to IR wavelengths.

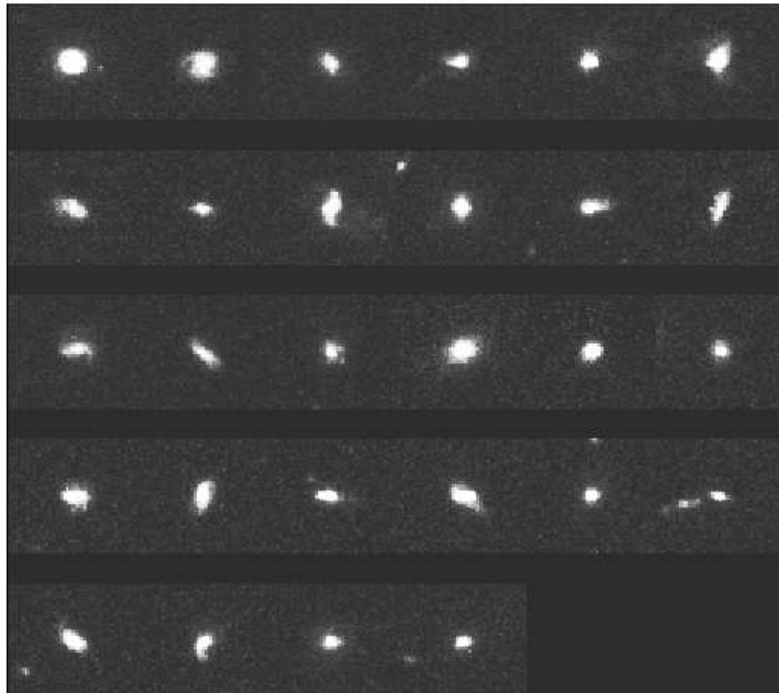


Figure 3. 28 compact galaxies with  $z > 0.4$ ,  $M_B < -20.5$  and color bluer than an Sbc. Each stamp has a size of  $40 h_{50}^{-1} \text{kpc}$ , and galaxies are shown by increasing redshift ( $z=0.4$  in the top left,  $z=1$  in the bottom right).

These galaxies represents 4% of the luminous ( $M_B < -20$ ) galaxy population, while they produce as many stars as the rest of galaxy population. Most of these star-forming galaxies  $0.5 \leq z \leq 1$ , appear to be strong mergers, or at least they show signs of interactions (Figure 4). It is important to notice that individual galaxies involved in these systems have sizes larger than the normal galaxy population (Figure 5). This argues in favor of the formation at  $z < 1$  of large systems, including massive ellipticals by merging of two large disks. Several large disks are also strong IR emitters, implying that UV luminosity samples only a small fraction of their star formation.

## 5. Conclusion

UV and IR luminosity density both present a surprisingly similar evolution since the last 9 Gyr. The former is dominated by a numerous population of blue galaxies, the latter is concentrated in a small fraction of the galaxy population, mostly interacting and dusty galaxies.

When looking at the morphological properties of the population responsible for the luminosity density evolution, UV and IR selected galaxies draw strikingly

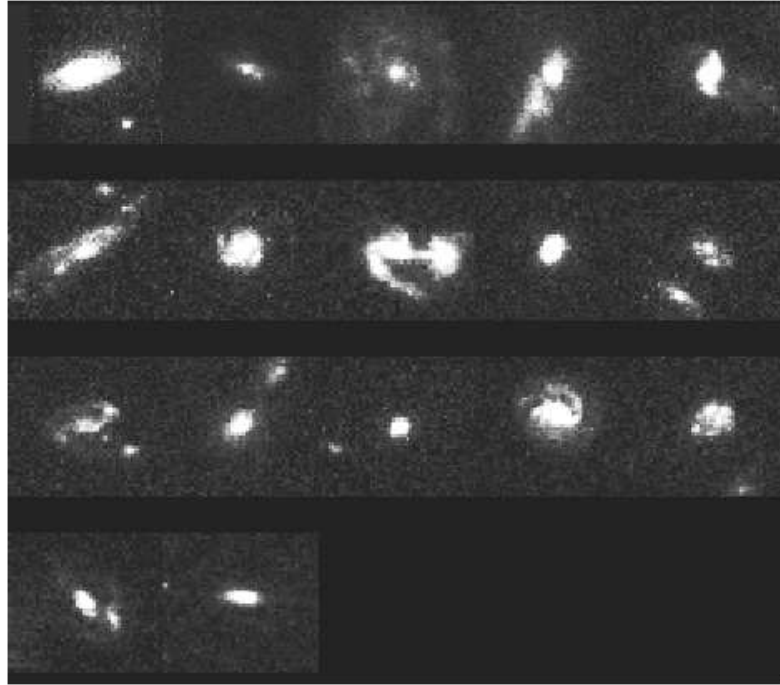


Figure 4. 17 starburst galaxies with  $f_{15\mu} \geq 350\mu\text{Jy}$  and/or  $f_{5\text{GHz}} \geq 16\mu\text{Jy}$  from Flores et al (1999) and Flores and Hammer (2000, in preparation). Each stamp has a size of  $40 h_{50}^{-1}\text{kpc}$ , and galaxies are shown by increasing redshift ( $z=0.4$  in the top left,  $z=1$  in the bottom right).

different pictures:

- Large galaxies -elliptical and large disks- have blue or UV properties almost unchanged since  $z=1$ , and most of the reported evolution in the UV is related to irregular and compact galaxies.

- Conversely, most of the galaxies responsible for the IR luminosity density evolution, are large galaxies (from S0 to Sbc), generally found in interacting systems; they include some good candidates to the formation of a massive elliptical at  $z < 1$  resulting from the collapse of two disk galaxies.

It is too premature to test which scenario -monolithic collapse or hierarchical model- is dominating the galaxy formation. But there is good evidence that at least, galaxy interactions were still at work in the latest 9 Gyr to form massive galaxies. Larger samples and better spectroscopic resolution are required to quantify the above observational facts.

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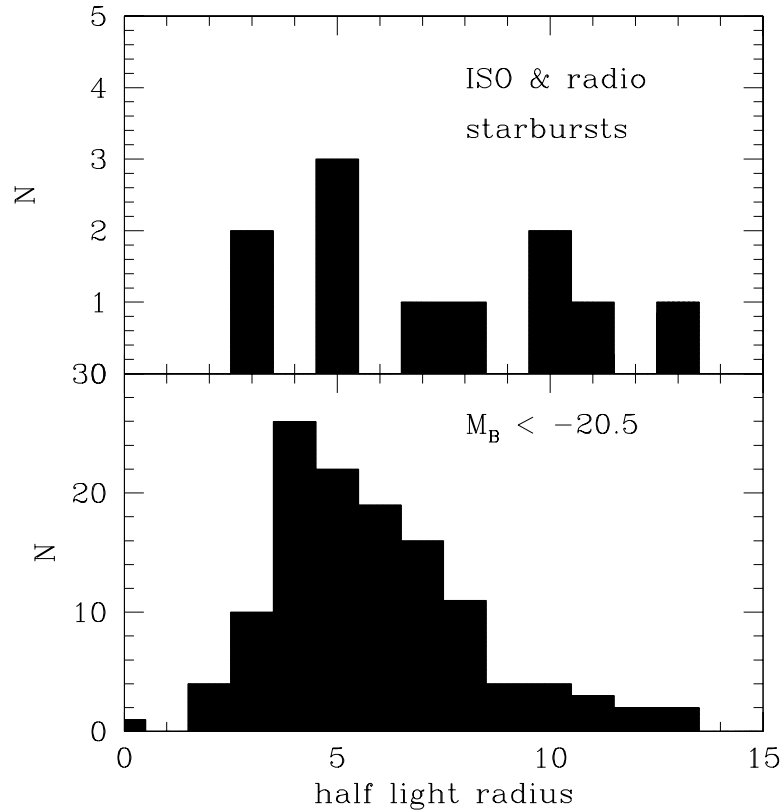


Figure 5. (top) Half light radius distribution for starburst galaxies detected by ISO and VLA. Only the major component in the interacting system is taken into account. (bottom) Same distribution for all CFRS galaxies with  $M_B \leq -20.5$  and  $0.4 < z < 1$ .

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